**Agrobiodiversity and a sustainable food future**



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# Integrative Sciences in the Plant Biodiversity Agenda for Humanity's Sustainable Food Future

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**The biodiversity of food plants is vital for humanity's capacity to meet sustainability challenges. Advancing this research requires rigorous integration of the plant sciences with the environmental, social, and health sciences. Integrative research is coalescing around four thematic cornerstones that are interdisciplinary and policy-relevant.**

The agricultural and food sciences are leading the way in how food and crop production utilize plant biodiversity. But, the world's sustainable food future also requires prioritizing the role of plant biodiversity in response to global changes that range from climate and environmental impacts to market integration, demographic and nutritional transitions, and human health challenges. The broad scope of this sustainability challenge highlights the need to involve the environmental, social, and health sciences in policy- and management-relevant research on the use and conservation of food plant biodiversity (agrobiodiversity).

Integrative scientific and scholarly approaches demonstrate coalescence around four thematic cornerstones that yield new insights and policy recommendations on agrobiodiversity (Figure 1):

(i) evolution, genetic resources, and ecology;
(ii) governance policy, institutions, and legal agreements;
(iii) human health, nutrition and disease; and
(iv) social-ecological interactions amid global change drivers.

These four cornerstones show expanding research, policy, and management activities involving agrobiodiversity, with the rate of scientific and scholarly research increasing significantly in recent years (Figure 1). Activities within and among these cornerstones are guiding current initiatives. Recently the international forum on "Agrobiodiversity in the 21$^{st}$ Century" has utilized the framework of these four cornerstones and the growing bridges among them to bring together 35 leading scientists and practitioners from the plant sciences and genetic resources as well as the ecological, social, and health sciences. This framework can serve productively to advance new integrative scientific approaches, as we expand upon below.

Advances based on integrative approach both within and among the four cornerstones are needed to guide the consolidation of research gains and the identification of strategies that can transform the contributions of agrobiodiversity to global food sustainability. Integrative approaches involving these four cornerstones also reflect the need for policy- and management-relevant research on the complex roles of smallholder and indigenous people in food biodiversity and security. Smallholder and indigenous groups are key stakeholders. Their knowledge and management account for the majority of the production and consumption of global food plant biodiversity that is conserved in current use. They also form a major segment of the food-insecure, malnourished, and impoverished population of the world.

## Evolution, Genetic Resources, and Ecology

Applying genomic, geospatial, and ecological tools is yielding new insights on agrobiodiversity in farming landscapes and food systems worldwide. Based on evolutionary ecology, genetic analysis, and agricultural and landscape ecology these insights range from the gene level to ecosystem- and global-scale synthesis propelled by the increase of high-quality scientific information on multi-level environmental functionality and cultural interactions (Vigouroux et al. 2011; Wood et al. 2015). These advances are vital to spatial and timeline comparisons of diversity in key hotspots through systematic monitoring of the status and coverage of *in situ* management and *ex situ* genebank collections. Globally the highest levels of agrobiodiversity occur in the farm ecosystems and surrounding landscapes of smallholder and indigenous populations (Jackson et al. 2012).

These advances are needed to document adaptive population-level shifts of *in situ* agrobiodiversity in response to global change and use of *ex situ* materials through genetic enhancement and crop improvement. It requires integrated analysis of the history and evolution of the genepools plant and animal genepools amid cultural interactions and knowledge systems (Van Andel et al. 2016). In the case of crop wild relatives (CWR), recent scientific advances and improved global-scale geospatial information have enabled high resolution *ex situ* gap analysis (Castañeda-Álvarez et al. 2016). New genomic tools and systematic monitoring methods are enabling refined baseline knowledge of the genetic diversity patterns of the landrace populations of local crops and CWR that continue to be managed and conserved *in situ*. In general, genomics advances also bridge to each of the other cornerstones treated below.

Integrated scientific approaches are needed to understand the natural and cultural dynamics of current agrobiodiversity evolution and ecology. Insights drawing on new research tools and spatially explicit models are being applied to the evolutionary ecology of food plants in environmental and sociocultural spaces subject to climate change and market integration (Mercer & Perales 2010; Orozco-Ramírez et al. 2016). Genetic resources and crop conservation science similarly require the role of integrative sciences. Recent repatriations of genebank accessions to farmers in Peru, Brazil, and India, for example, raise new questions concerning whether and how crop biodiversity can be inputted into production systems subject to climate change and whether such flows are reaching farmers on a demand basis include those affected by agrobiodiversity loss. Future research essentially requires the expansion of systematic agrobiodiversity monitoring at benchmark observatories and through interinstitutional global data networking.

## Governance Challenges and Opportunities

The portfolio of policy, legal, and institutional mechanisms for the governance of agrobiodiversity has been broadened to involve multiple international arrangements on access and benefit sharing, including the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the Convention on Biological Diversity (CBD) together with the Nagoya Protocol, and the FAO's Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture. However, the lagging pace of implementation reflects an overall crisis in this governance. Benefits sharing has been widely touted but sparsely applied. In short, new strides in creating governance frameworks belies a significant operational deficit.

At the same time, community, grassroots, and civil society organizations along with the private sector are experimenting with innovative institutions and actions. Examples include seed associations, celebrity chefs, and corporate social responsibility agreements between companies and farmer groups. The informal sector, including farmer seed systems, continues to provide relatively low-cost seed through decentralized pathways (Jarvis et al. 2011). Many regions of food plant biodiversity rely on robust informal seed networks and could benefit from quality improvements that incorporate their strengths. Needed information on region-scale seed systems is a gap in scientific research that to-date has favored the more tractable community and national levels.

Advances in new scientific technologies that are largely unattended in current treaties exert expanding governance challenges. OMICS information involving whole-genome sequences, proteomes and unique processes of metabolites, particularly those produced through culturally guided evolution of plant biodiversity, is adding a critical new dimension to governance. It also includes access to the information of selected gene sequences and mutations found in local crops, seed, or wild relatives in cultural landscapes. The complexity of these scientific and social issues requires interdisciplinary research extending from the plant sciences to the social sciences.

## Human Health, Nutrition and Disease

Ending hunger, achieving food security and improving nutrition and health are highlighted in sustainability mandates, such as the new UN "2030 Agenda for Sustainable Development," that call for the use of biological diversity in consumer-accessible food systems and dietary diversity. Yet scientific findings underscore that while agrobiodiversity is significantly varied among certain consumer groups and regions within countries (Aguilar et al. 2015), even in the world's industrialized economies, these estimates show the overall trend toward reduced levels at the global scale and within most countries (IPES-Food 2016).

One force promoting agrobiodiversity in healthy diets is the resilient preference for biodiversity-related traits in many local farming and food systems (Johns et al. 2013). Food biodiversity at the farm level can support the nutrient, organism, and community levels of dietary diversity, especially when combined with informed food choices and specialization that provides income for market-based purchasing power (Davis et al. 2012; Sibhatu et al. 2015). The coupling of plant biodiversity in present and past foodways, diet, nutrition, and health outcomes requires expanded scientific focus linking taxonomic, functional group, and geographic levels to whole-diet and food-system approaches (McKey et al. 2010).

Integrative approaches are vital to addressing the decoupling of agrobiodiversity production and consumption. This decoupling occurs where growers in certain regions within the global centers of concentrated agricultural biodiversity (aka Vavilov centers) may not be able to access these foodstuffs due to insufficient resources and dietary shifts that include the global nutrition transition. Many such cultivators are smallholders and indigenous people. Plant sciences integrated with environmental, social, and health sciences are required for policy-relevant research on improving the linkages of agrobiodiversity to nutrition and health in these regions (Jones et al. 2014).

## Social-Ecological Interactions amid Global Change Drivers

Drivers of global change are triggering either the loss, enrichment or conservation of the biodiversity of agriculture and food. These drivers include global climate change, demography, land use intensification, and the large-scale integration of food systems and global markets, as well as urbanization, peri-urban expansion, and national planning. In the case of climate change, the modelling of crop yield underscores that the variety- and species-level adaptations (Challinor et al. 2014) will depend on the strategic insertion of biodiversity. Climate change challenges correspond to agrobiodiversity systems as well as farmer knowledge systems (Bellon & van Etten 2014).

The integration of commodity markets has driven the national-level decline of farming populations as well as the biodiversity of global food systems (Khoury et al. 2015). The global integration of labor markets is similarly a driver. Countervailing trends occur at the local scales of individuals, households, and communities. The counter-tendencies suggest that favorable conditions such as farm-level resource availability and resilient cultural preferences can effectively promote agrobiodiversity use and conservation in these contexts.

The interactions of multiple drivers determine whether agrobiodiversity is conserved and, if so, how evolution is structured. Integrating the plant sciences with the environmental and social sciences is urgently needed to distinguish the specific regions and corresponding producer and consumer populations vulnerable to the loss and potential extinction of food plant biodiversity (Brush et al. 2015; Dyer et al. 2014), as well as food insecurity. Conversely, regional conditions enabling the compatibility of agrobiodiversity use with potential sustainable intensification also demand policy-relevant scientific analysis (Garnett et al. 2014; Zimmerer 2013). In geographic areas with the significant continued use of agrobiodiversity, non-static practices of cultural identity and ethnicity in smallholder, indigenous, and other groups tend to exert strong positive feedbacks.

## Discussion

The aforementioned research cornerstones and the interconnecting bridges are required to enhance the use of biological diversity in sustainable agricultural and food systems. Each of the four cornerstones is interdisciplinary, requiring the integration of the plant sciences with the environmental, social, and health sciences. The expanding scientific literature, as well as the recent Strüngmann forum, highlight that the scientific research in each cornerstone is distinguished by characteristic subject matter and scales (Figure 2). Linking across cornerstones is similarly needed to respond to key gaps and challenges facing policy-relevant agrobiodiversity research. One example is the impact of global drivers evident as powerful forces propelling changes in each of the four cornerstones. Thematic synthesis of research to-date shows characteristic scales, both spatial and temporal (Figure 2), revealing that studies of genetic resources and human health put greater emphasis on molecular and organism-scale processes with extensive time-frames dating to early agriculture. Less time-depth of within-country, region-scale research demonstrates a continued gap of research in each cornerstone.

## Conclusion

Integrating policy- and management-relevant research in the plant sciences with the environmental, social, and health sciences is paramount to the current and future initiatives needed to advance the contributions of biodiversity to the sustainability of agriculture and food systems. Future developments will require more integrative scientific approaches and new research strategies. Powerful linkages are expanding, such as the influence of genomics research and the increasingly influential role of the drivers of global change. Recognizing the linkages within and among the four principal cornerstones in an integrated, co-evolving framework, rather than rigid delimitation, is emphasized. The dynamic roles of smallholders and indigenous groups are an important priority in research on agrobiodiversity and food sustainability amid expanding global changes.

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## Figures

Figure 1. Annual Estimates and the Growth of Publications in Biological Diversity in Agriculture and Food Systems in General (dark blue on the far right) and in Cornerstone Scientific Areas (see legend), 2000-2015, Data from Web of Science, Accessed.

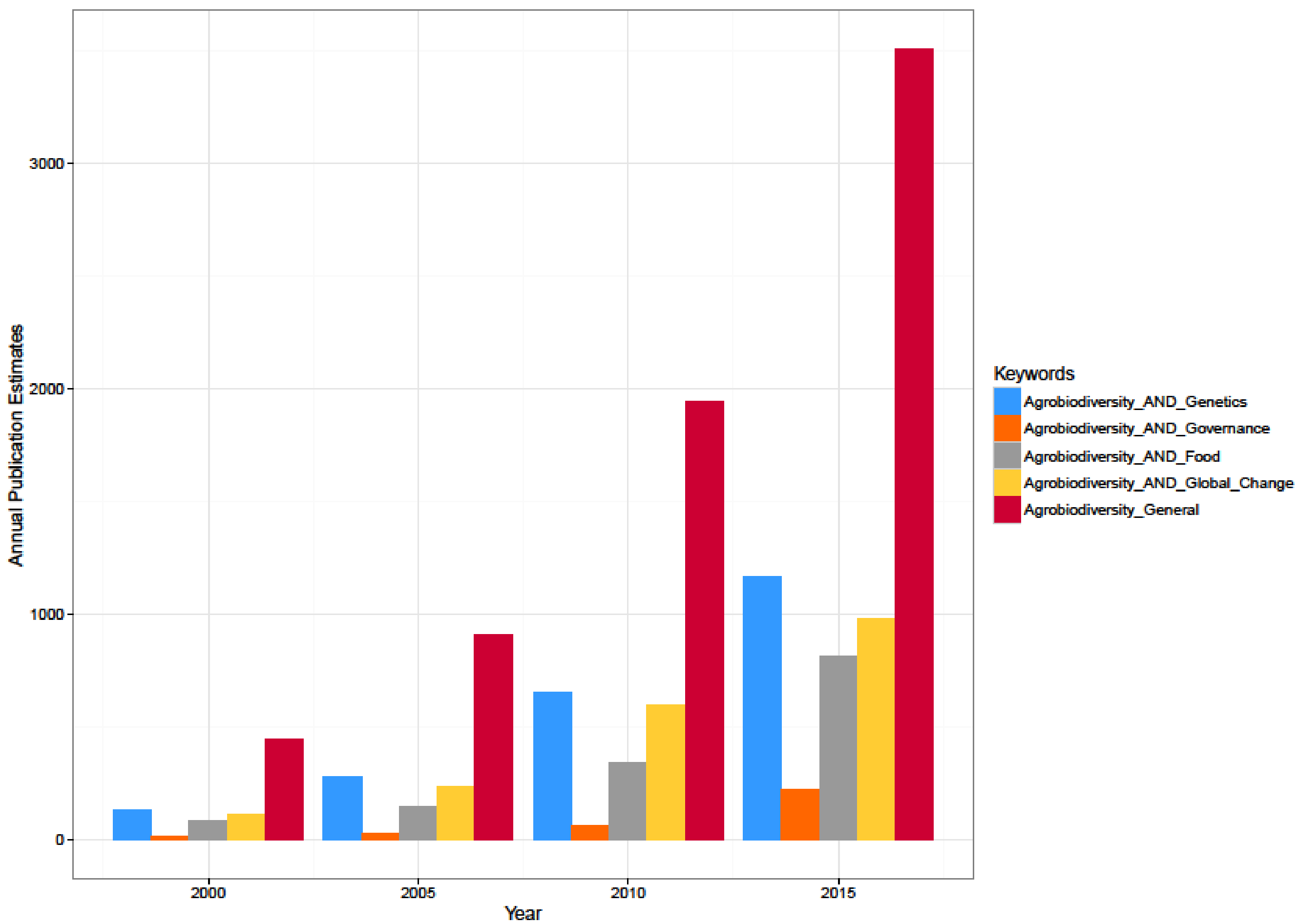

Figure 2. Characteristics of Spatial and Temporal Scale in Research on the Cornerstone Themes of the Biological Diversity of Agriculture and Food Systems (Agrobiodiversity)